

# Frame Rate and Human Vision

Andrew B. Watson  
NASA

Ames Research Center  
Moffett Field, CA  
[andrew.b.watson@nasa.gov](mailto:andrew.b.watson@nasa.gov)

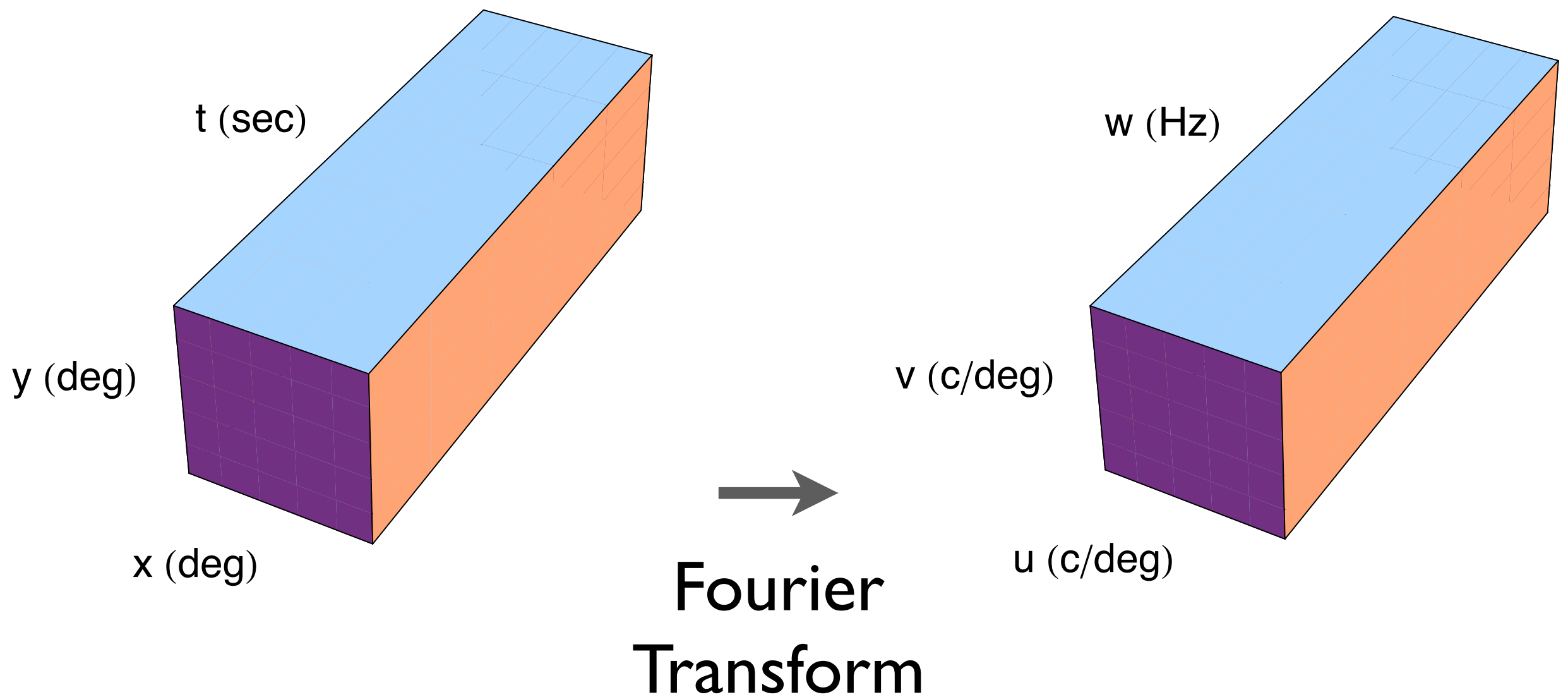
# Stroboscopic Displays

- All cinema and video is stroboscopic
- A sequence of still images



Lumière Cinématographe, 1896


# Movies in the Frequency Domain



# Spatio-temporal frequencies



Frequency (cy/deg) = 4.00  +

Orientation (°) = 0.00  +

Contrast = 1.00  +

color

G

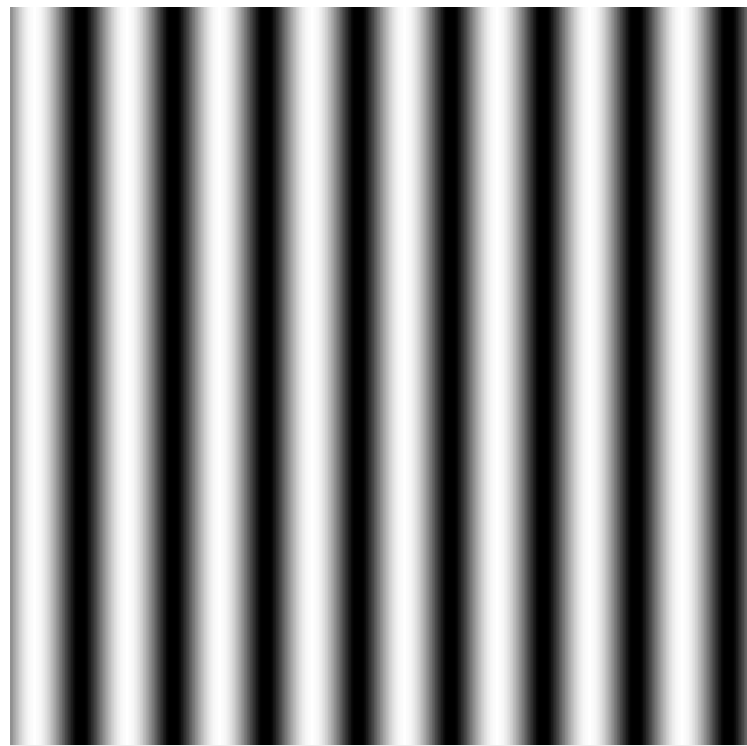
R/G

B/Y

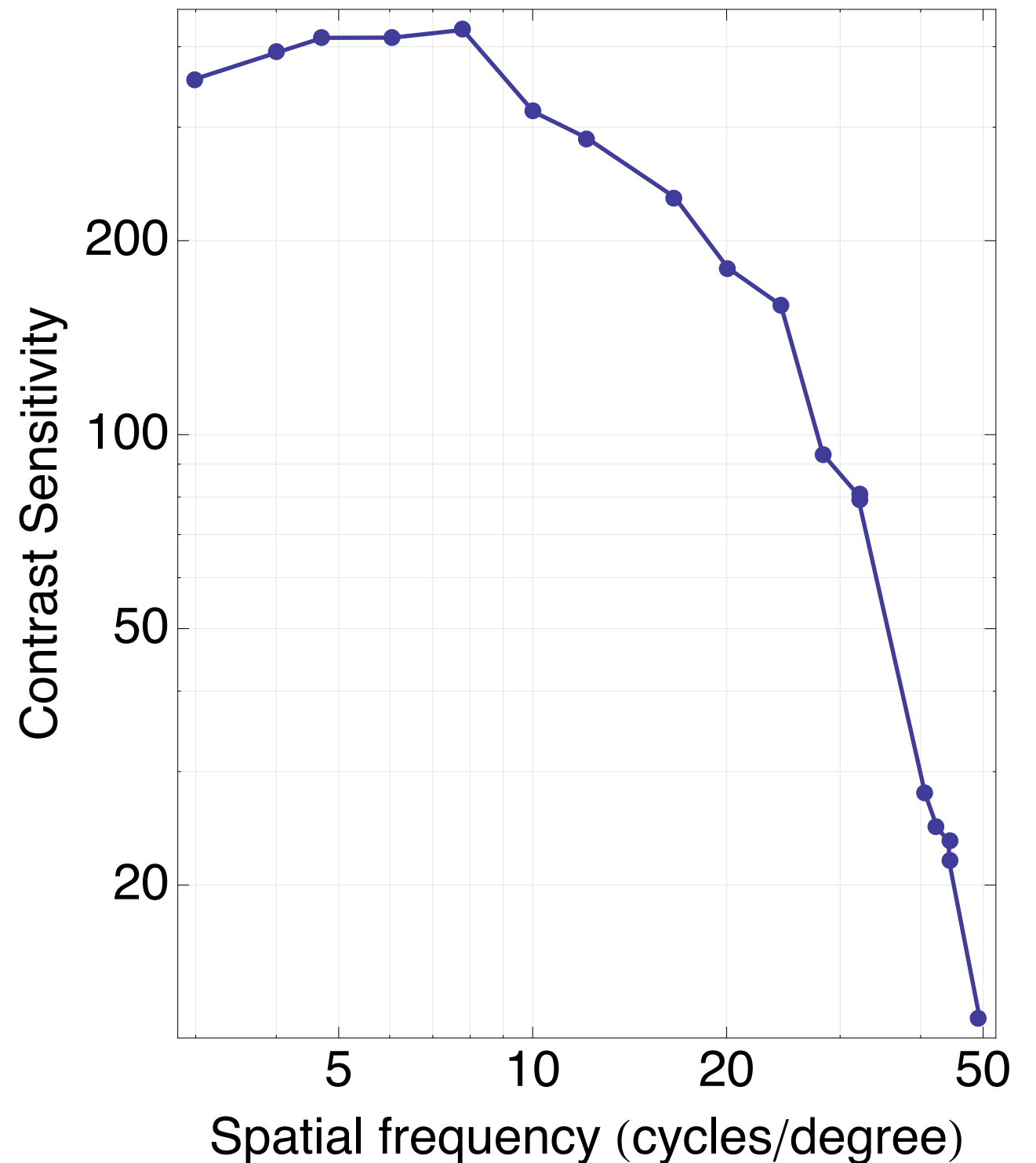


# Spatial CSF

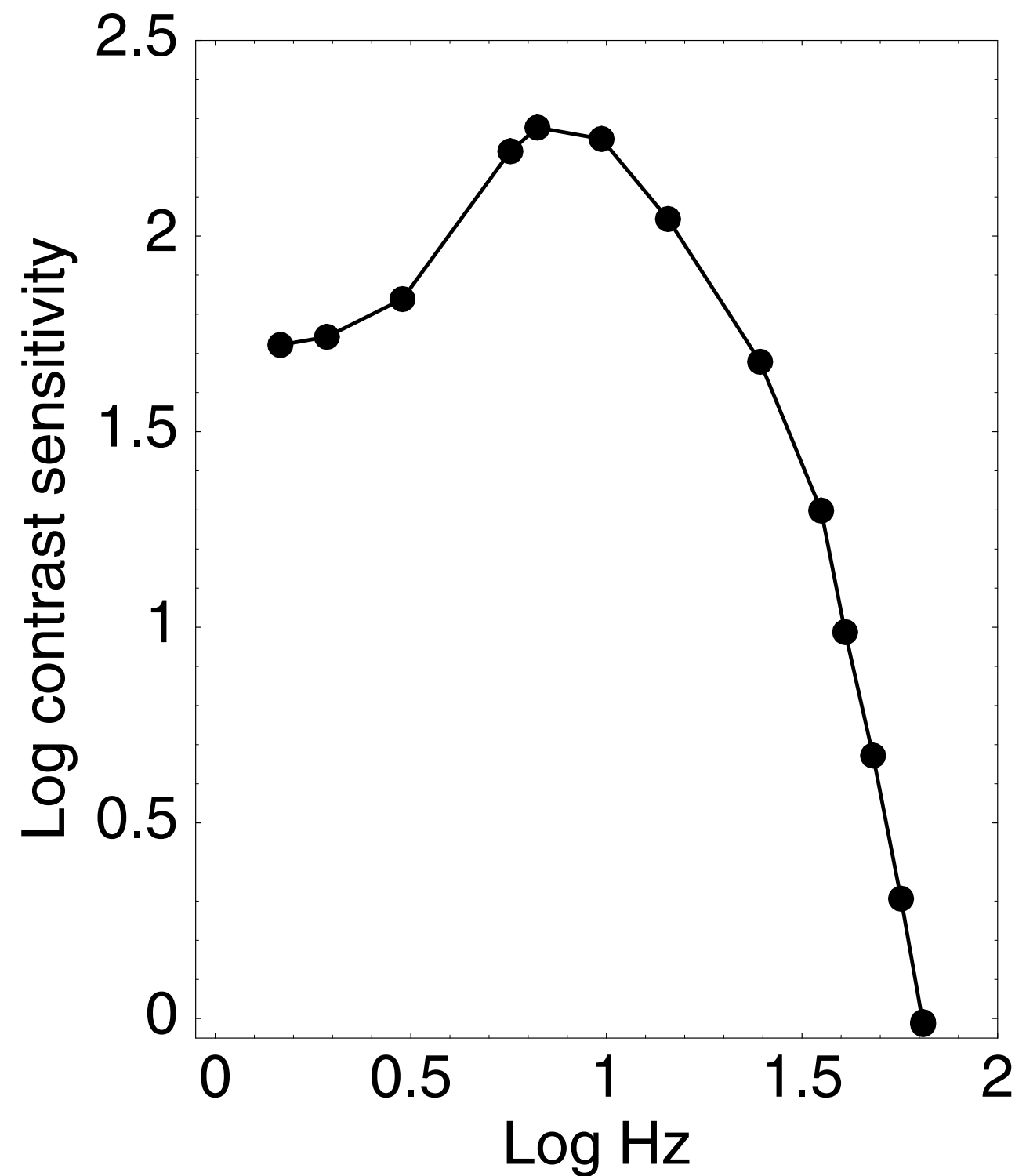
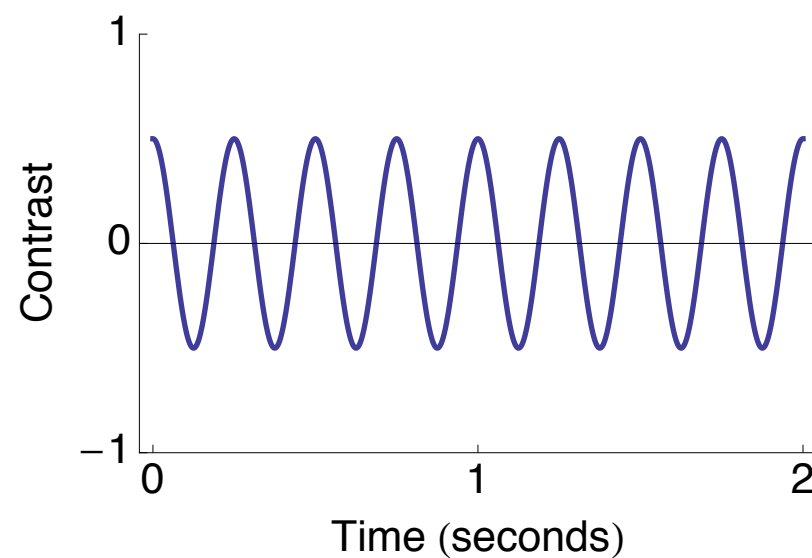
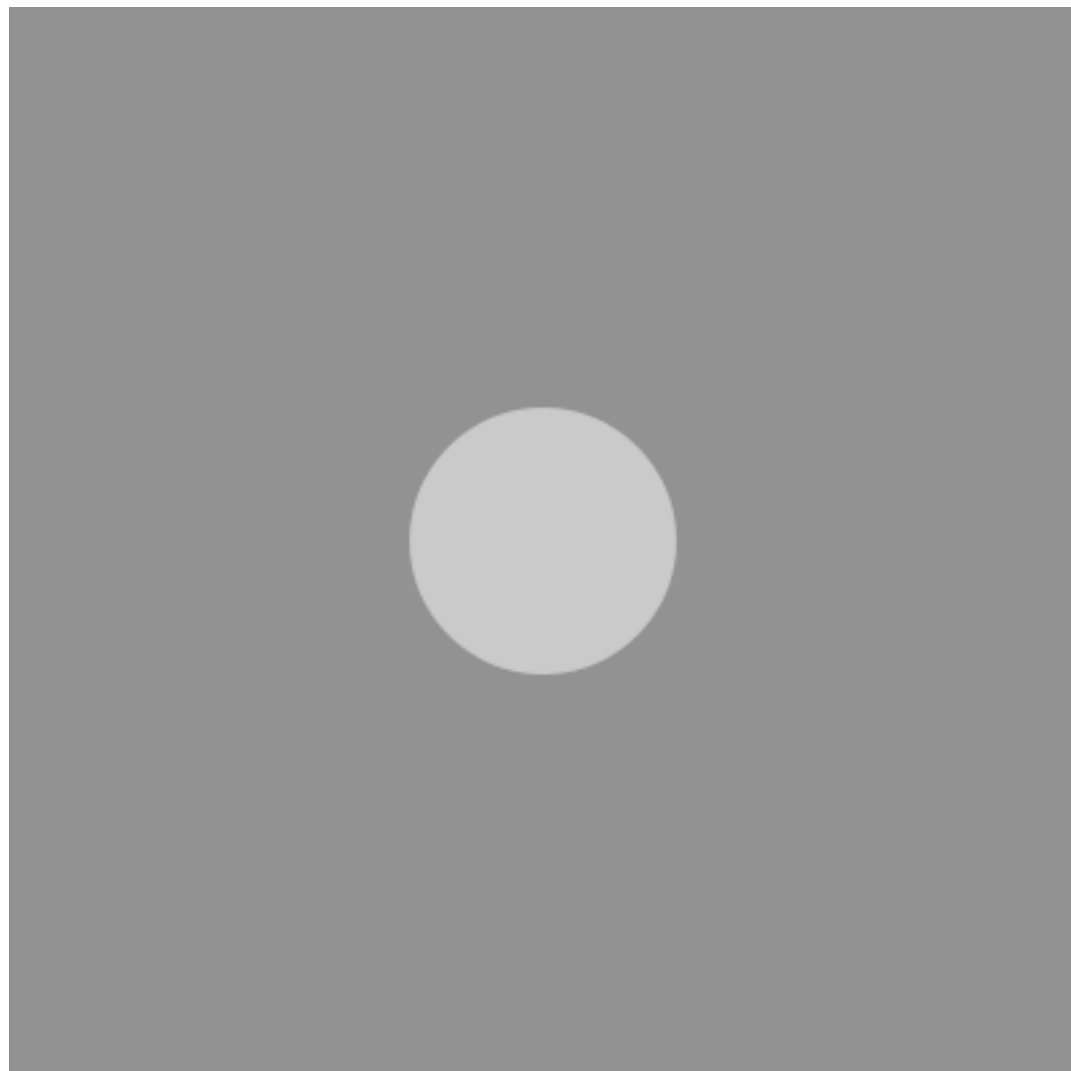
8 cycles/degree



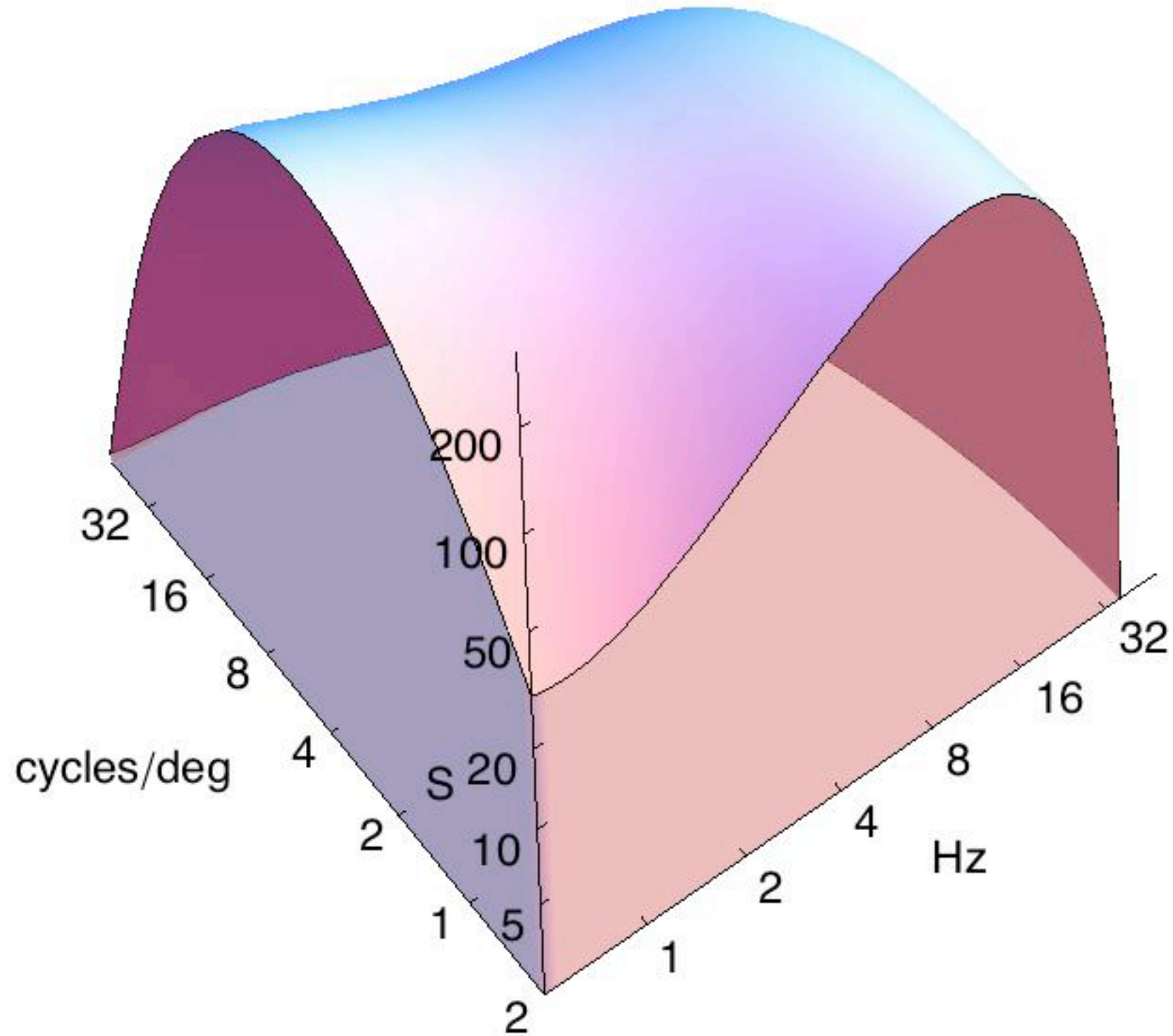
1 degree



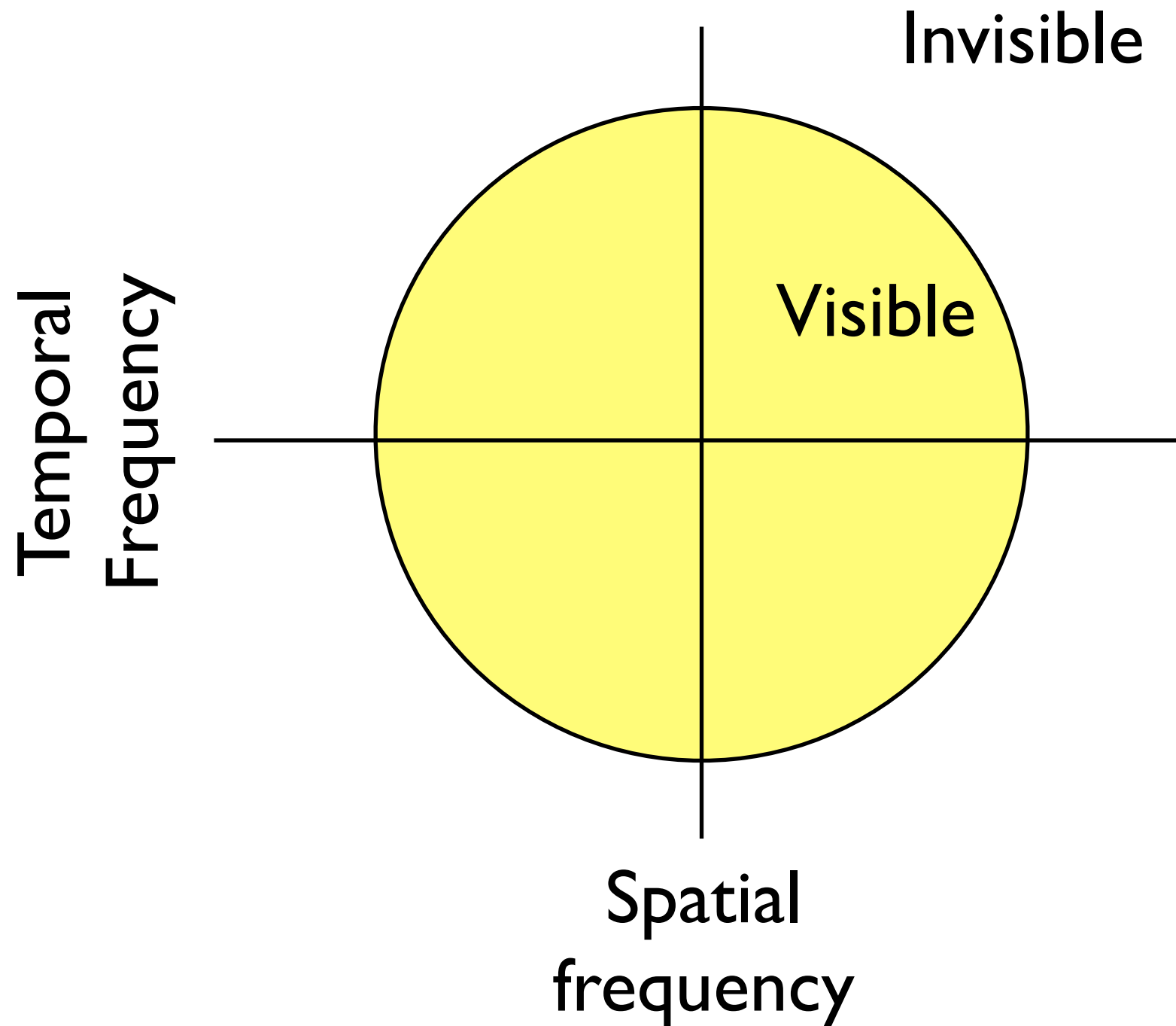
# Temporal CSF



# Spatio-Temporal CSF



# Window of Visibility

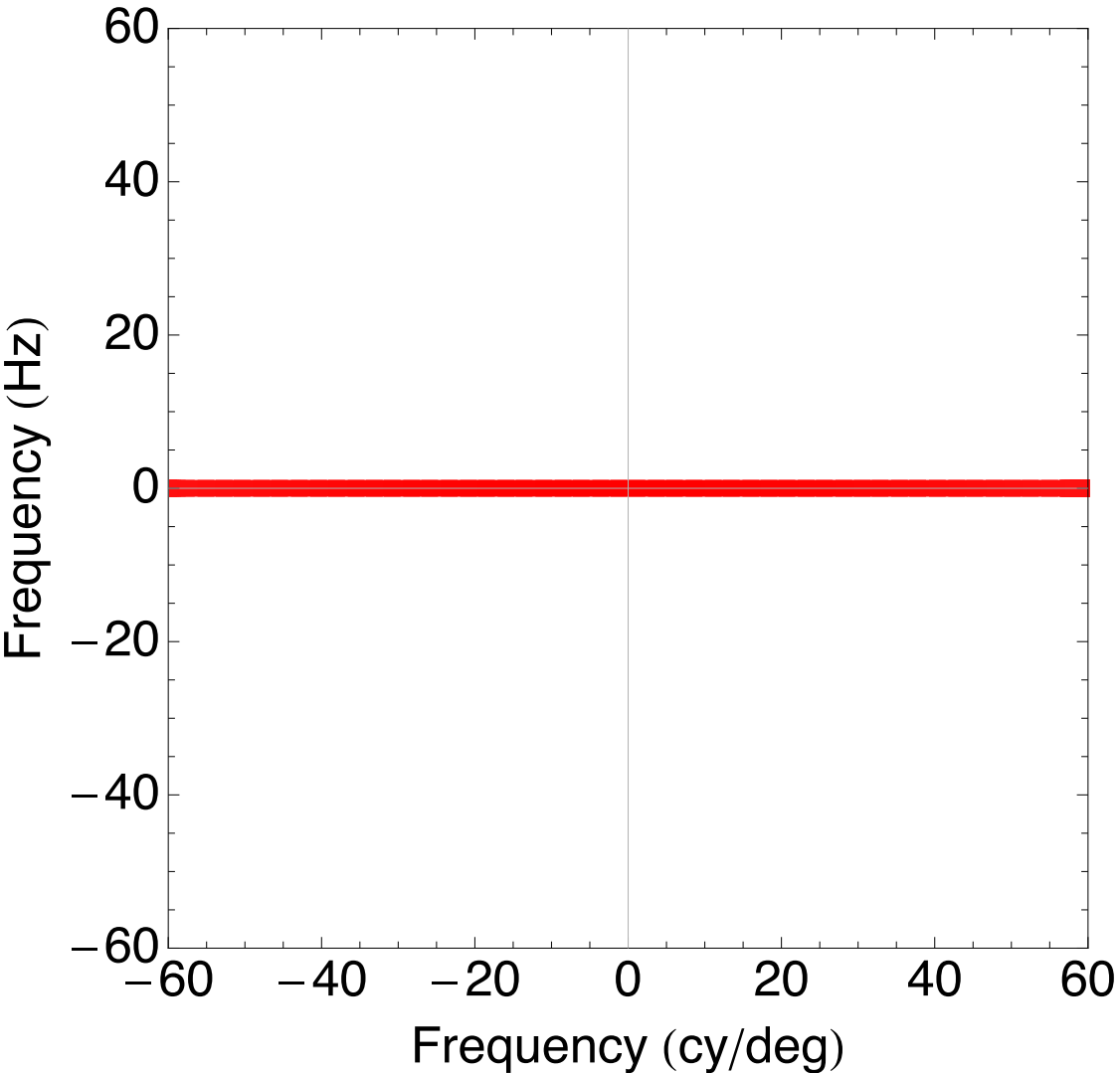
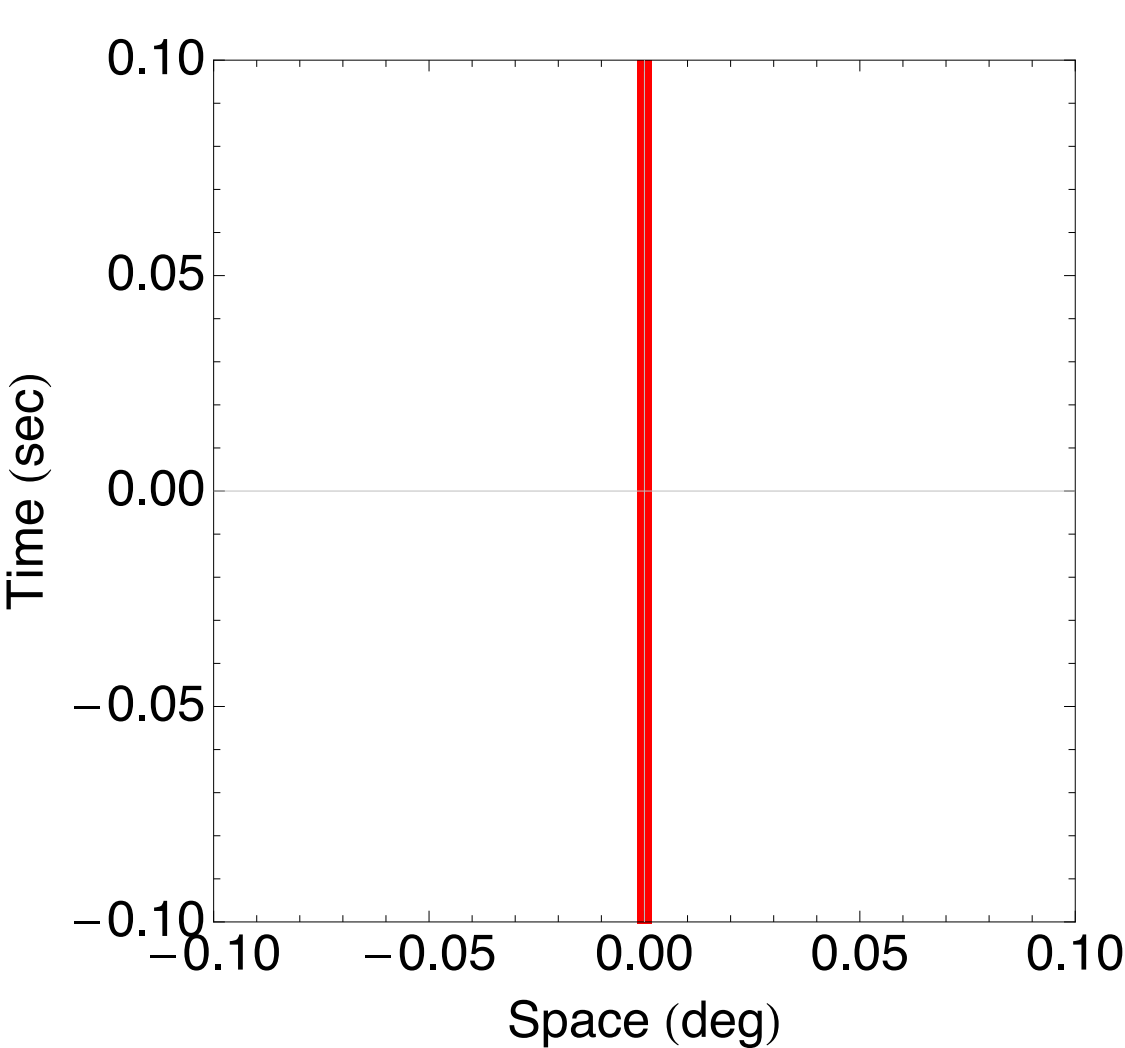




# Moving line



# Window of Visibility



Speed (deg/sec) = 0.00

Frame rate (Hz) = 240.

Shutter (frames) = 1.00

Blur (deg/60) = 0.20

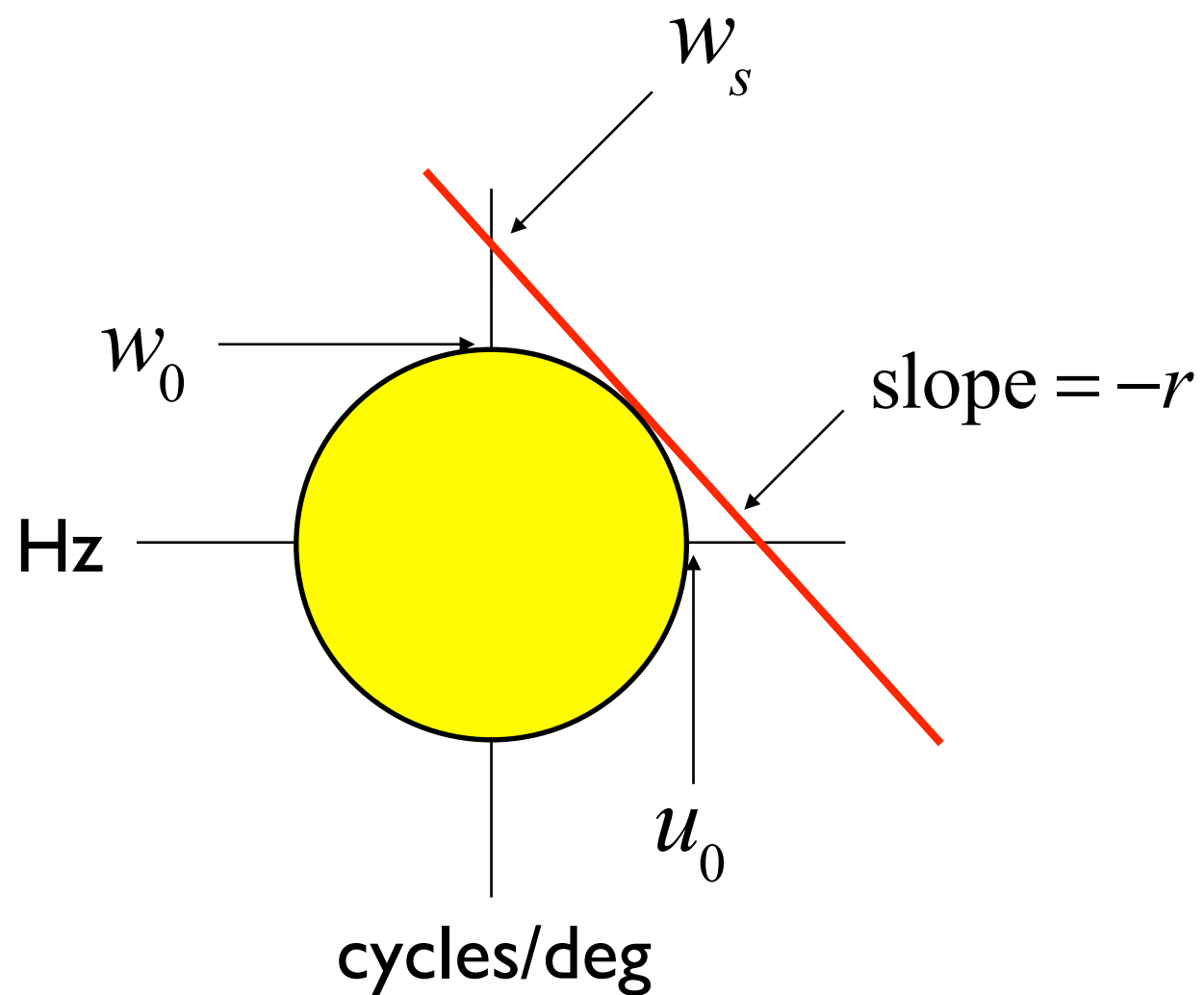
Hold (fields) = 1.00

Flicker (≠ fields) ☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5

Sampled ☐

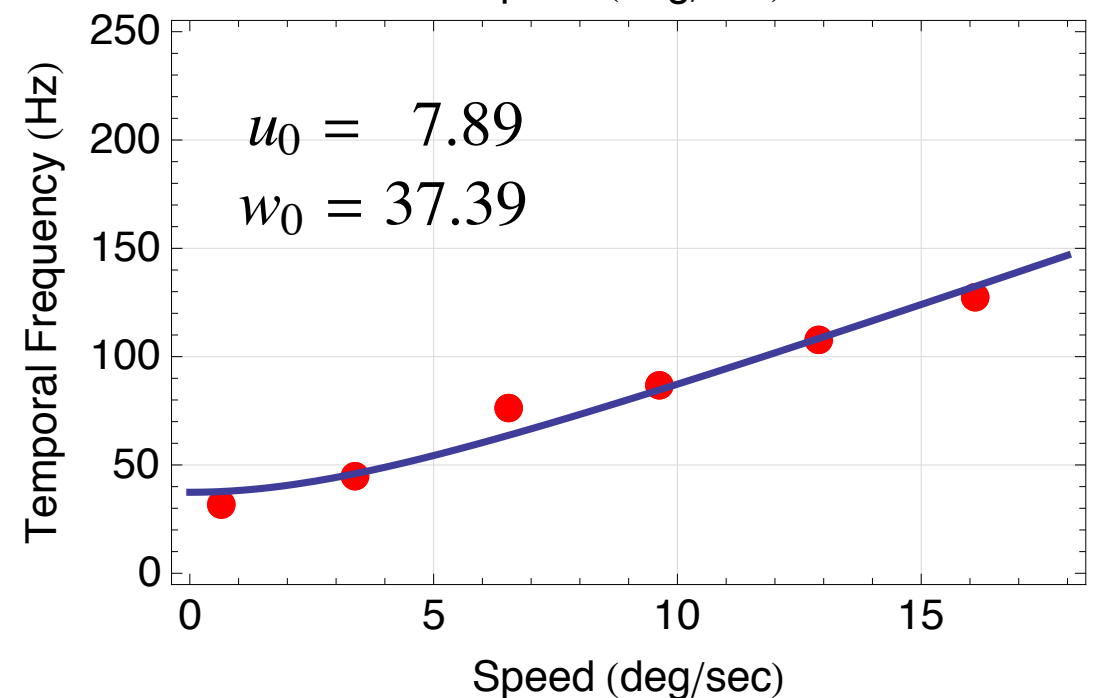
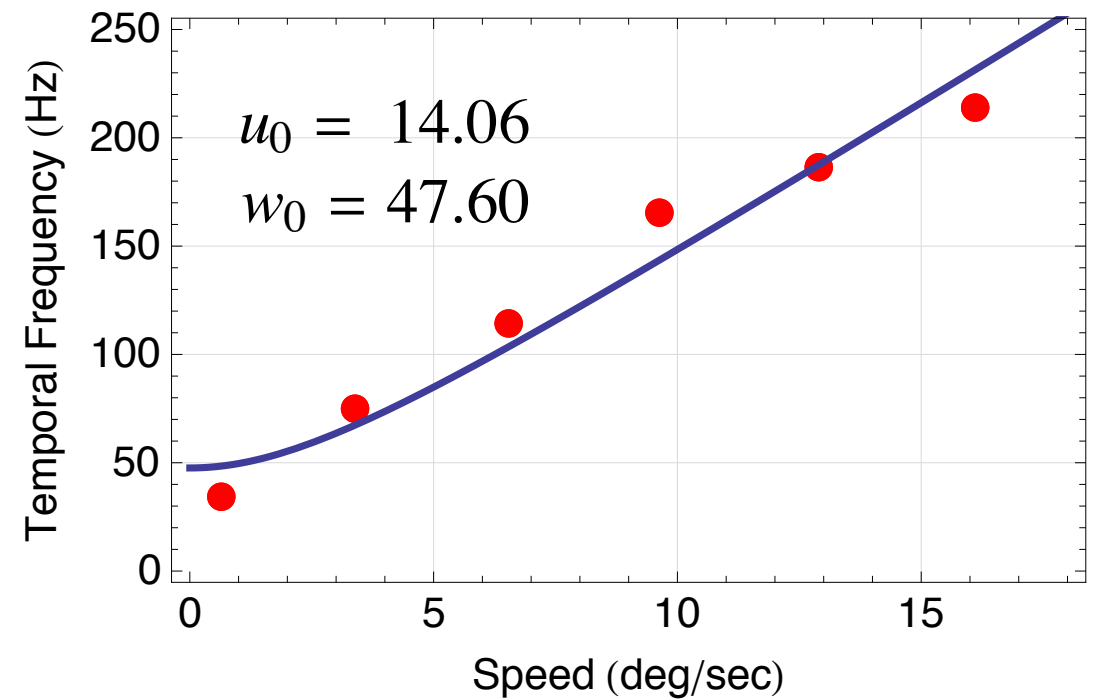
# Critical Frame Rate

## Theory



$$w_s = \sqrt{r^2 u_0^2 + w_0^2}$$

## Data



# Preliminary Summary

- Understanding the spatio-temporal frequency spectrum of the source,
- and the spatio-temporal frequency sensitivity of the human,
- allows you to predict the required frame rate.

# Effects

- Object spectrum
- Camera blur
- Exposure duration
- Display hold
- Display flicker
- Brightness
- Color
- Eye movements

# Math

object    motion    exposure    sampling    flicker    hold

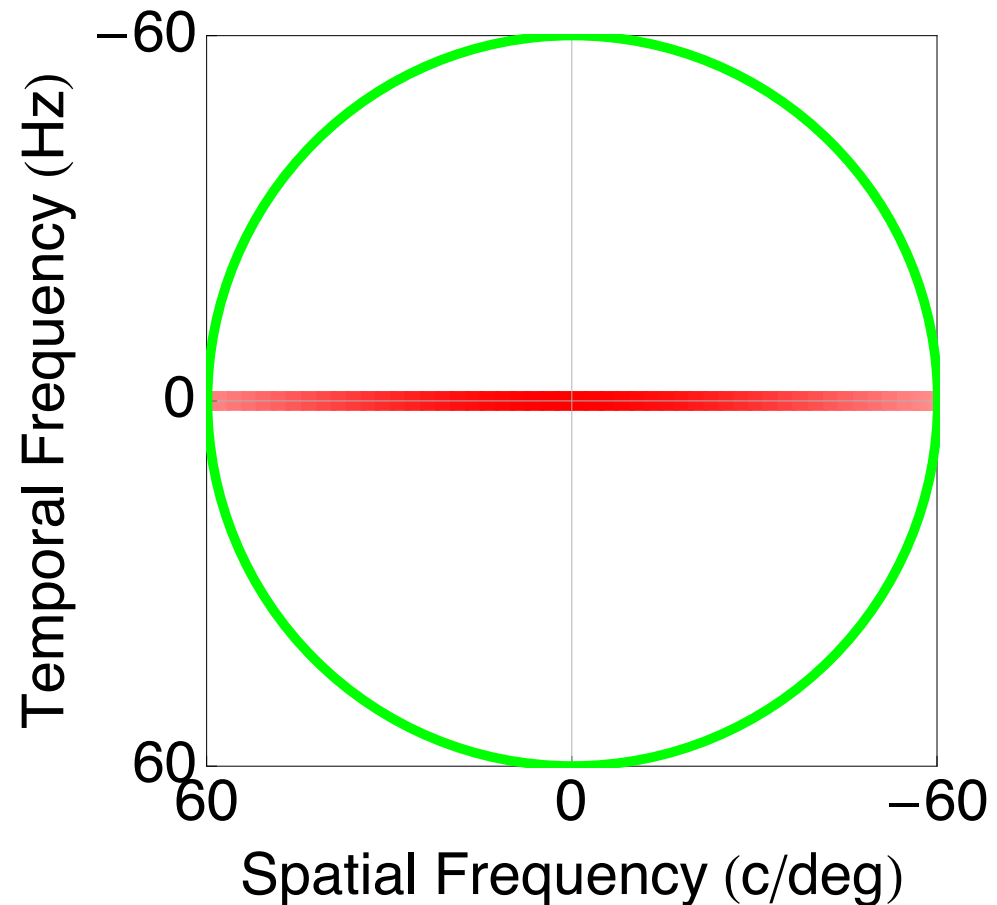
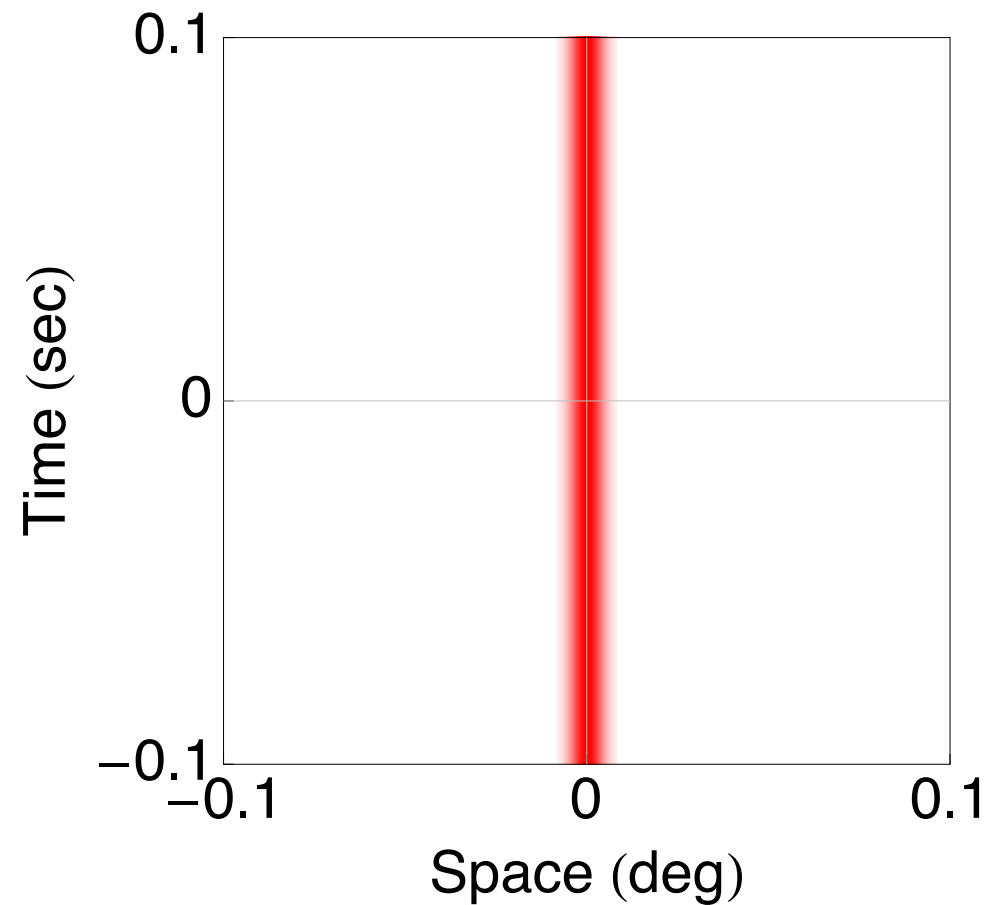
↓       ↓       ↓       ↓       ↓       ↓

$$\left( \left( \left( o(x) * m(x, t) \right) * e(t) \right) s(t) \right) * f(t) * h(t)$$

Fourier  
Transform

$$\left( \left( O(u) M(u, w) E(w) \right) * S(w) \right) H(w) F(w)$$

# Window of Visibility



Speed (deg/sec) = 0.00  +

Frame rate (Hz) = 240.  +

Shutter (Frames) = 0.10  +

Blur (deg/60) = 0.50  +

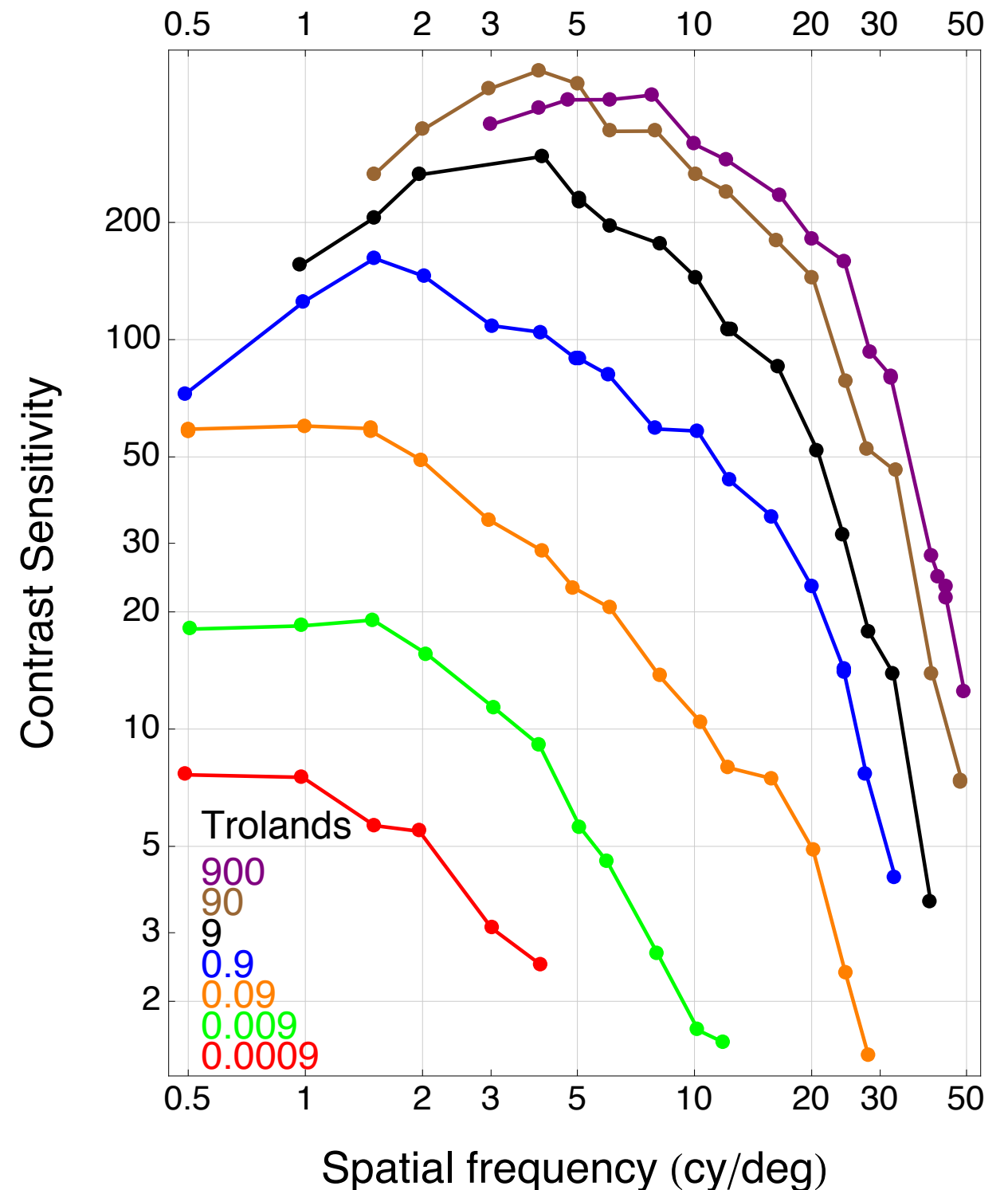
Hold (Fields) = 0.10  +

Flicker fields ☒ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5

Sampled ☐

# SCSF vs Illuminance

- Dimmer backgrounds
- reduce sensitivity
- decrease resolution
- Asymptotes at high brightness

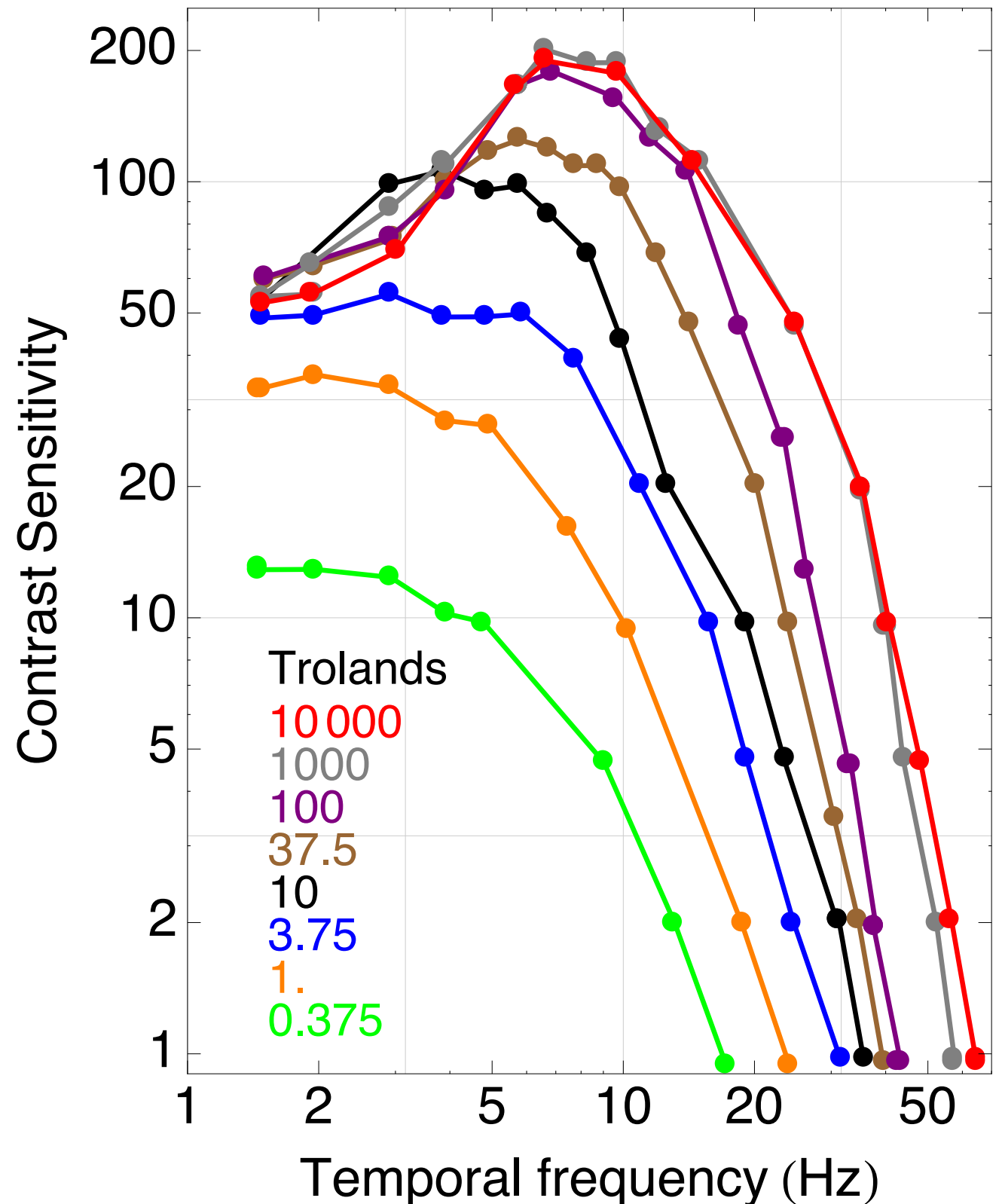


Data from Van Nes & Bouman (1967)



# TCSF vs Illuminance

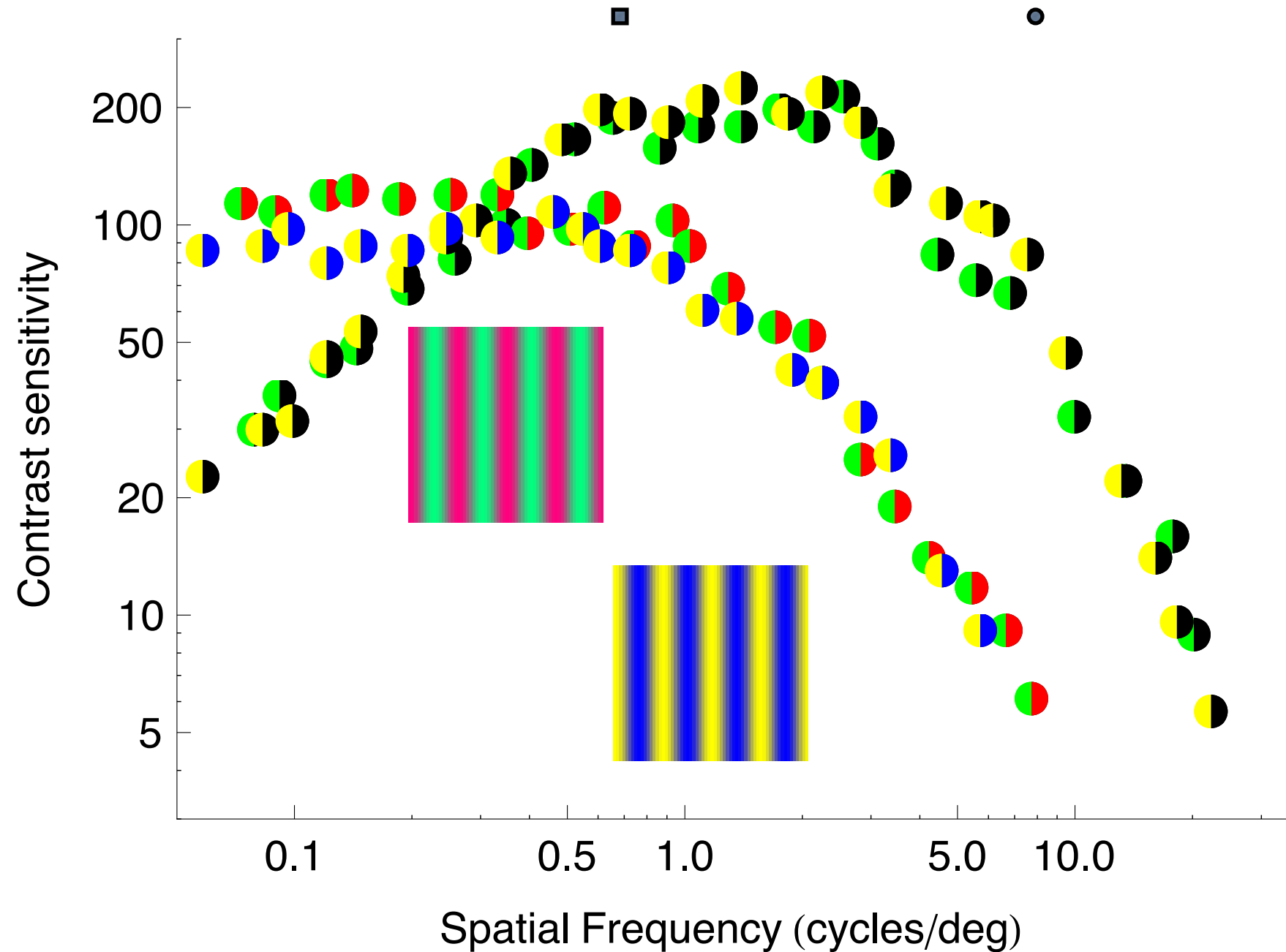
- Dimmer backgrounds
- reduce sensitivity
- decrease resolution
- Asymptotes at high brightness



*Data from De Lange (1958)*

# SCSF vs Color

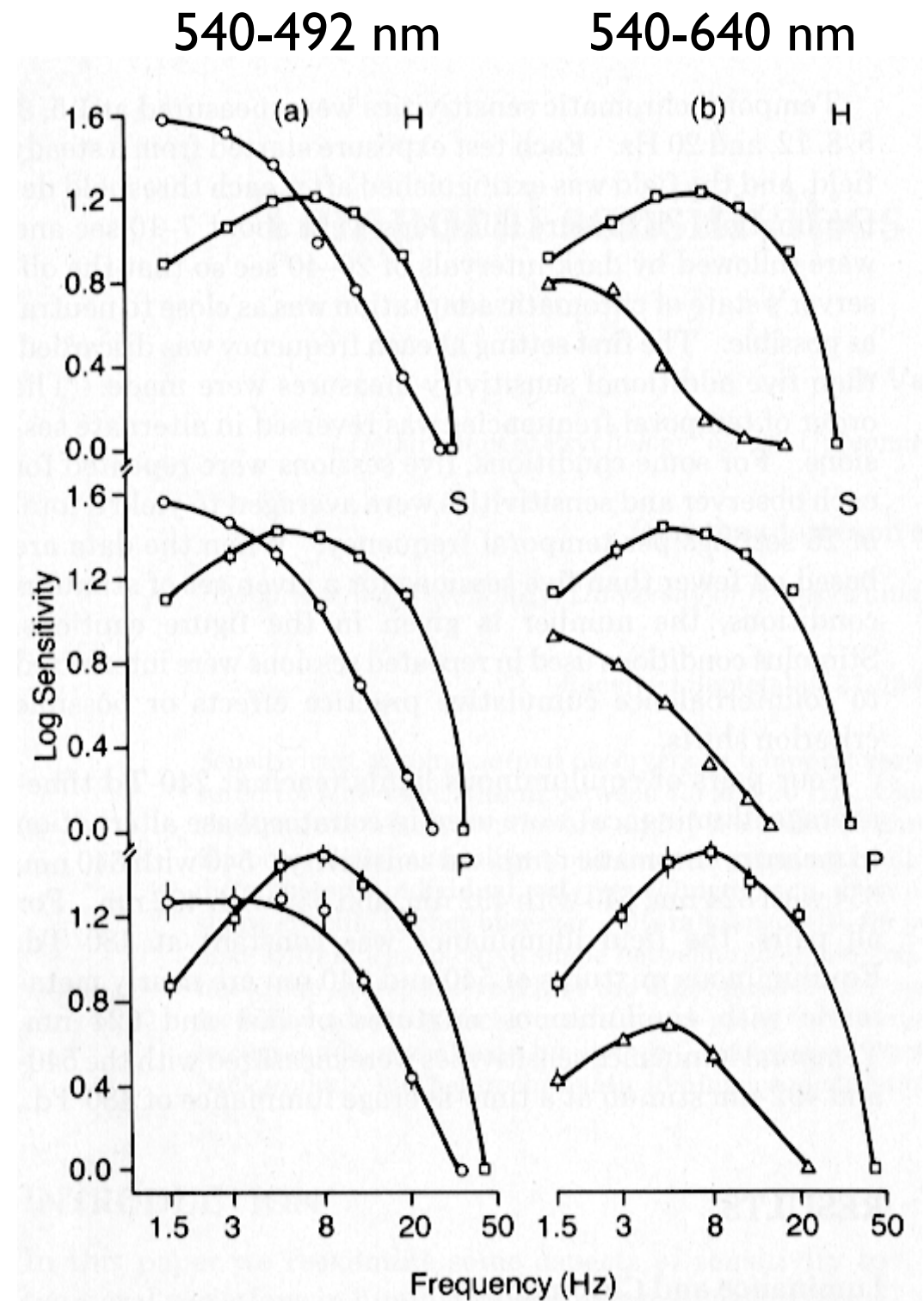
- Color modulation
- lower sensitivity
- lower resolution



Mullen, K.T. (1985). The contrast sensitivity of human color vision to red/green and blue/yellow chromatic gratings. *Journal of Physiology, Lond.* 359(381-400).

# TCSF vs Color

- Color modulation yields lower temporal resolution
- Luminance and Chromaticity sensitivities for two color directions and three observers.

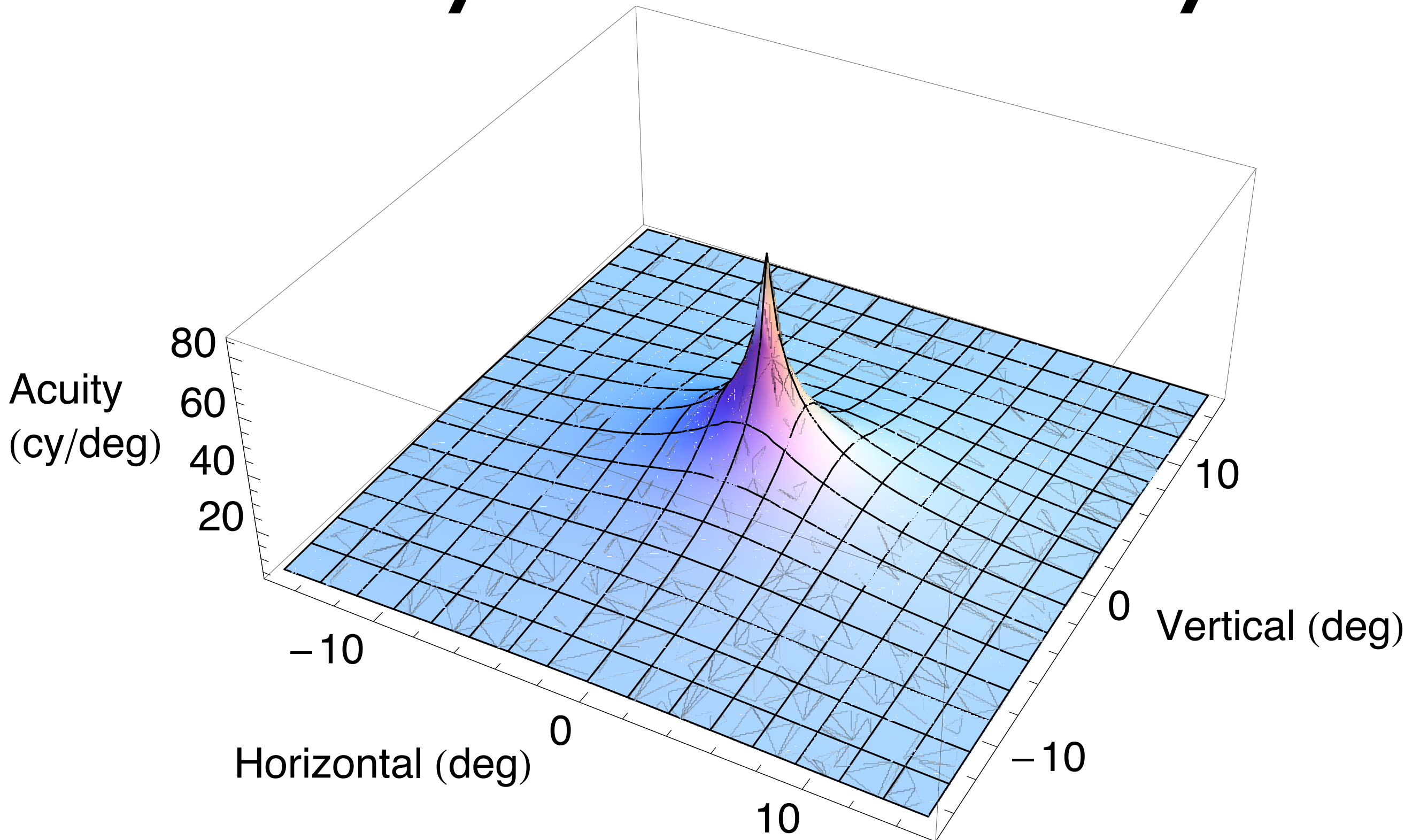


From Varner (1984)

# Effects on Window Size

- Dimmer → smaller
- Color → smaller
- Periphery → smaller
- Smaller window → fewer visible artifacts

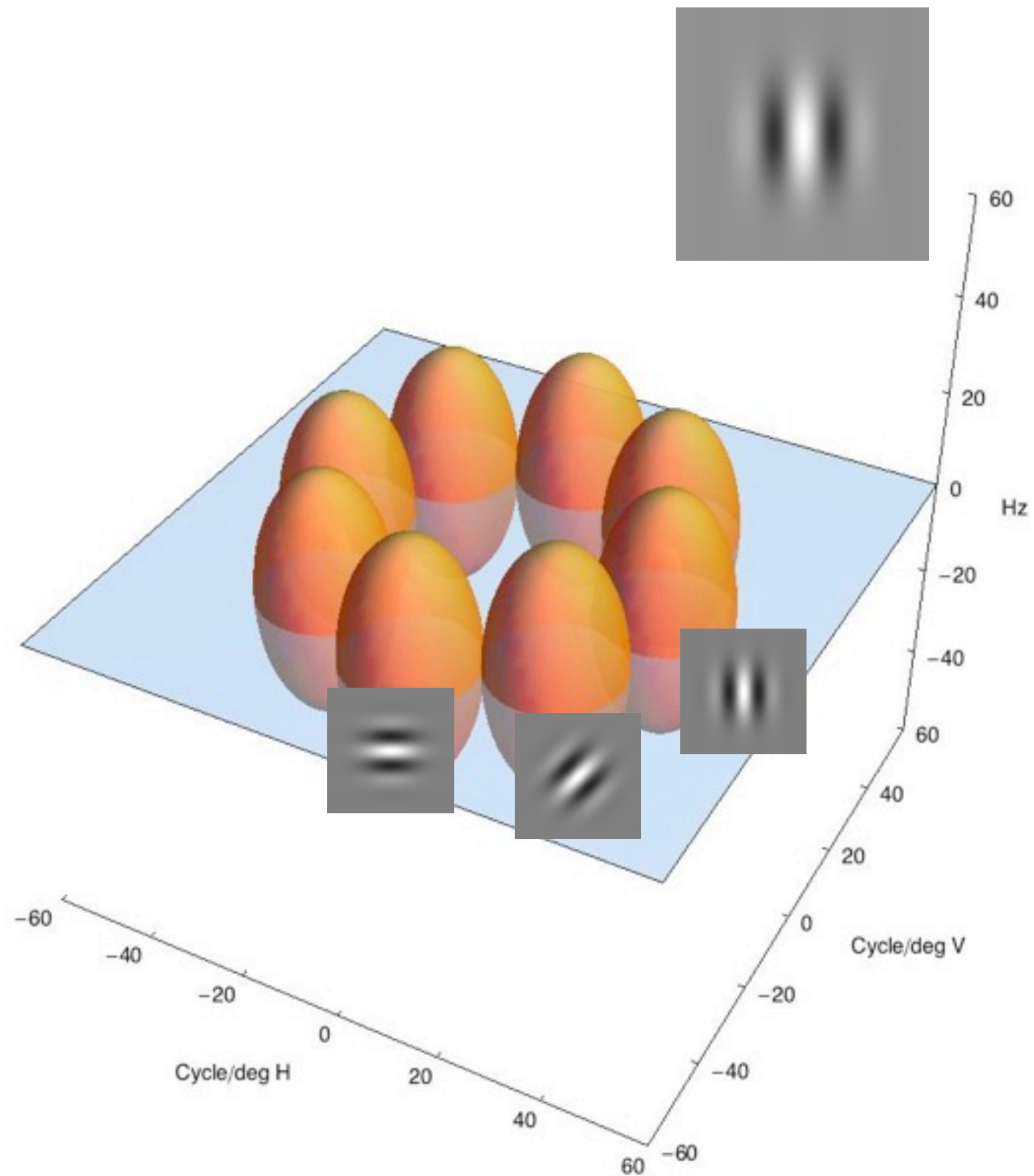
# Acuity vs Eccentricity



# Eye-movements

- Visual system responds to retinal image motion
- When the eye tracks an object, its retinal motion is reduced or eliminated
- Other objects are not tracked, but they lie in the low-resolution periphery

# Channels



# Summary

- Window of Visibility predicts frame rate effects
- Can incorporate effects of content, camera, display & observer
- Benefits may be greater in coding than in capture



# References

- De Lange, H. (1958). Research into the dynamic nature of the human fovea-cortex systems with intermittent and modulated light. I. Attenuation characteristics with white and colored light. *Journal of the Optical Society of America A*, 48, 777-784.
- Mullen, K. T. (1985). The contrast sensitivity of human colour vision to red-green and blue-yellow chromatic gratings. *Journal of Physiology*, 359, 381-400.
- Patterson, R. (2009). Review Paper: Human factors of stereo displays: An update. *Journal of the Society for Information Display*, 17(12), 987-996, <http://dx.doi.org/10.1889/JSID17.12.987>.
- van Nes, F. L., Koenderink, J. J., Nas, H., & Bouman, M. A. (1967). Spatiotemporal modulation transfer in the human eye. *Journal of the Optical Society of America A*, 57, 1082-1088.
- van Nes, F. L., & Bouman, M. A. (1967). Spatial modulation transfer in the human eye. *Journal of the Optical Society of America A*, 57, 401-406.
- Varner, D. (1984). Temporal sensitivities related to color theory. *Journal of the Optical Society of America A*, 1, 474-481.
- Watson, A. B., Ahumada, A. J., Jr., & Farrell, J. (1986). Window of visibility: psychophysical theory of fidelity in time-sampled visual motion displays. *Journal of the Optical Society of America A*, 3(3), 300-307, <http://www.opticsinfobase.org/viewmedia.cfm?uri=josaa-3-3-300&seq=0>.
- Watson, A. B. (1986). *Temporal Sensitivity*. In K. Boff, L. Kaufman & J. Thomas (Eds.), *Handbook of Perception and Human Performance*. New York: Wiley.
- Watson, A. B. (1990). Perceptual-components architecture for digital video. *Journal of the Optical Society of America A*, 7(10), 1943-1954.
- Watson, A. B., & Yellott, J. I. (2012). A unified formula for light-adapted pupil size. *Journal of Vision*, 12(10), <http://journalofvision.org/12/10/12/>.